

Prospects for Higgs Discovery at the Tevatron

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for

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Outline

- Introduction
- Finding the Higgs at the Tevatron
- Standard Model Higgs Search
 - WH, ZH ($H \rightarrow bb$) Channels (low M_H)
 - $H \rightarrow WW^*$ Channels
 - ($M_H > 130$ Gev/c²)
- Projections for SUSY from SM Higgs results
- Summary

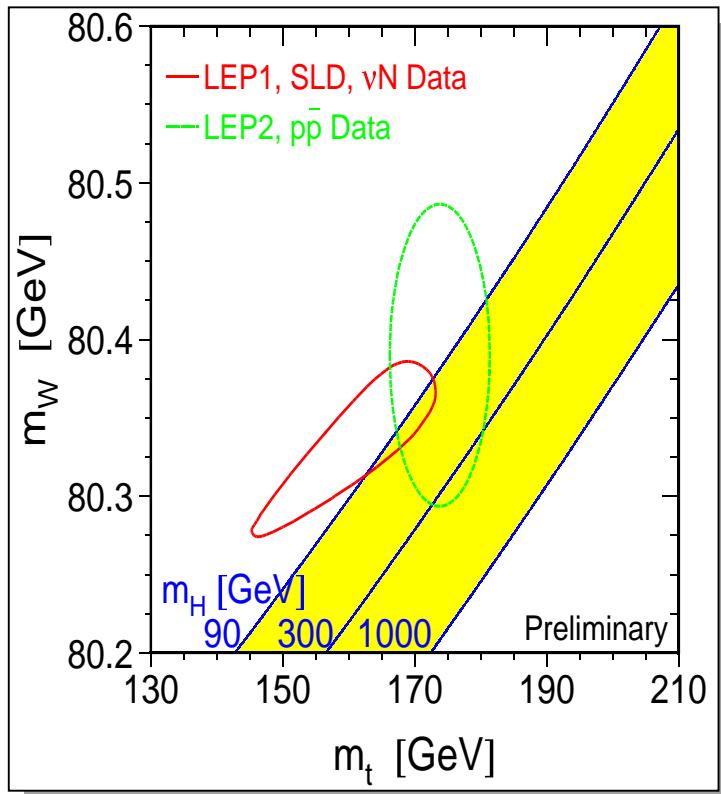
Introduction

- The Higgs boson(s) - vital ingredient(s) in the SM (SUSY)
- Provide a mechanism for EWSB
- LEP2 limits: $M_H > 95 \text{ GeV}/c^2$ at 95% C.L.
Could exclude upto $108 \text{ GeV}/c^2$
- LHC should be able to cover masses up to $\sim 1 \text{ TeV}/c^2$
- But in the interim period, there is a real possibility that the Higgs can be discovered at the Fermilab Tevatron!

Finding Higgs at the Tevatron: Motivation

● Experimental

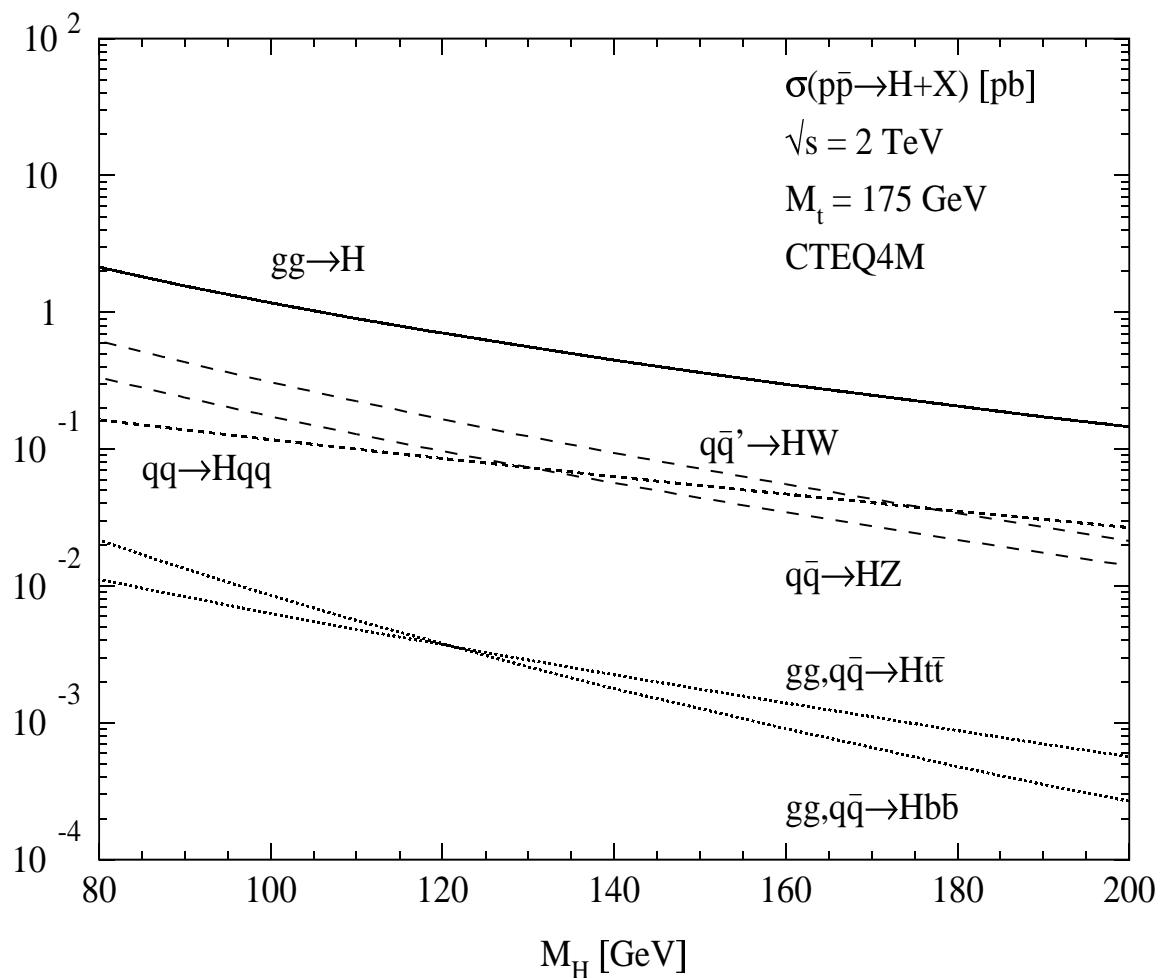
- The data from LEP, SLD and the Tevatron, when analyzed within the framework of the standard model (SM), favor a low-mass Higgs boson.



● Theoretical

- Many SUSY models predict a neutral Higgs boson with a mass less than about 130 GeV/c^2 .

Standard Model Higgs



- $gg \rightarrow H$ dominates, but difficult to see
- WH , ZH are most accessible
- SUSY enhances some cross sections!

Finding Higgs at the Tevatron

- Most promising: Associated Production with EW bosons

$$p\bar{p} \rightarrow$$

$$WH \rightarrow \ell\nu b\bar{b}$$

$$\rightarrow \ell\ell \bar{\nu}\bar{\nu},$$

$$\rightarrow \gamma\gamma$$

Particularly good for low mass ranges

- For $M_H > 135 \text{ GeV}/c^2$, can look at:

$$p\bar{p} \rightarrow gg \rightarrow H \rightarrow W^*W^* \rightarrow \ell\bar{\nu}\ell\nu, \ell\nu jj$$

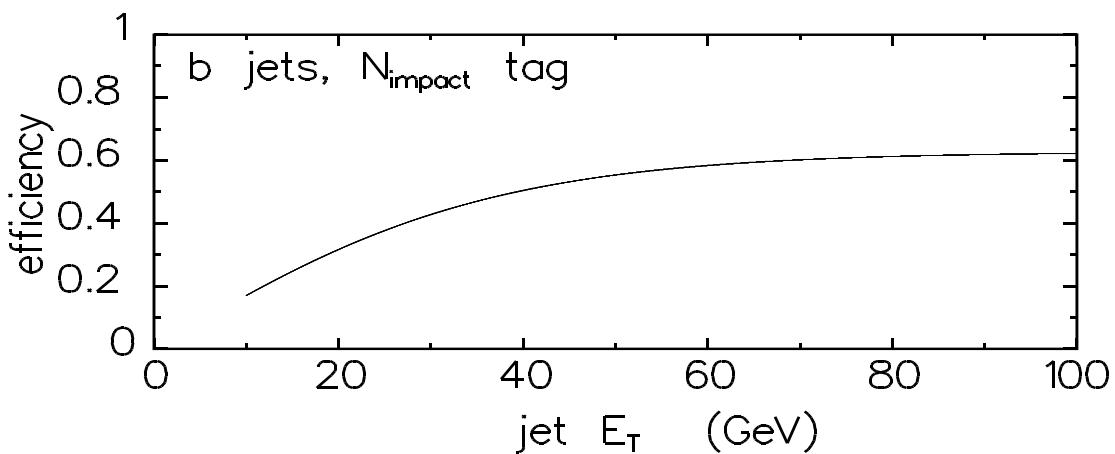
$$p\bar{p} \rightarrow WH \rightarrow WW^*W^* \rightarrow \ell\nu\ell\nu jj, \ell\nu\ell\nu\ell\nu$$

$$p\bar{p} \rightarrow ZH \rightarrow ZW^*W^* \rightarrow \ell\ell\ell\nu jj, \ell\ell\ell\nu\ell\nu$$

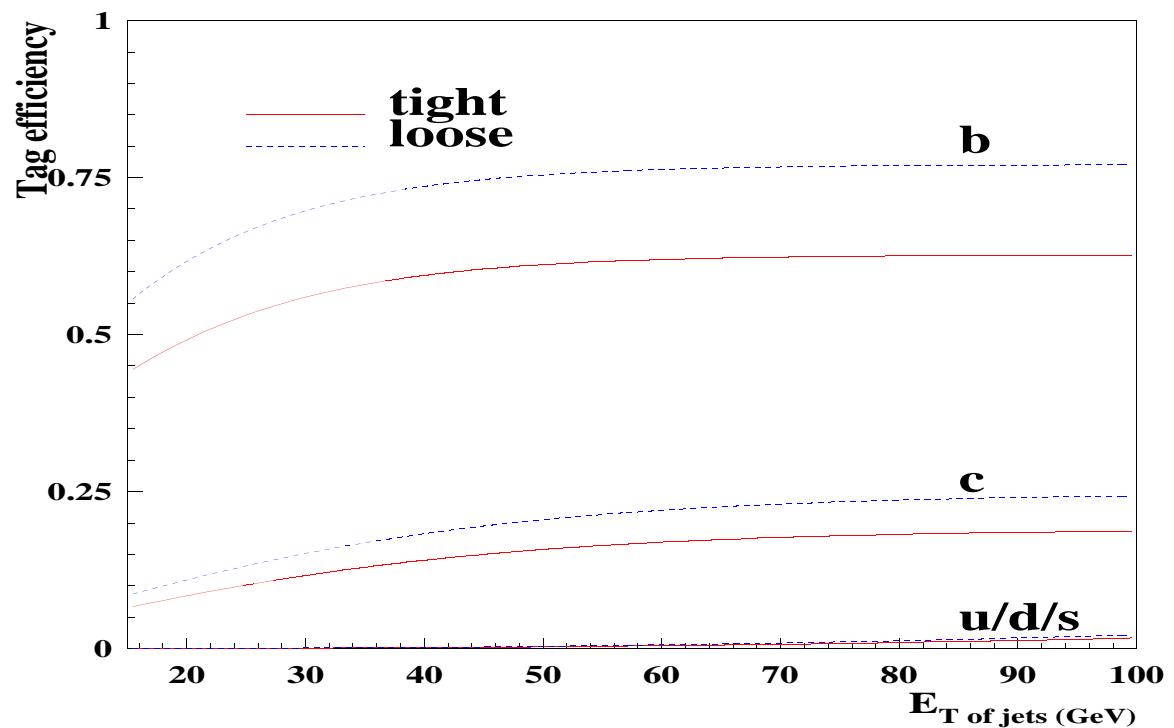
$$\text{Also, } p\bar{p} \rightarrow WH \rightarrow WZ^*Z^*, \quad p\bar{p} \rightarrow ZH \rightarrow ZZ^*Z^*$$

b-Tag Efficiency

SHW b tagging efficiency:

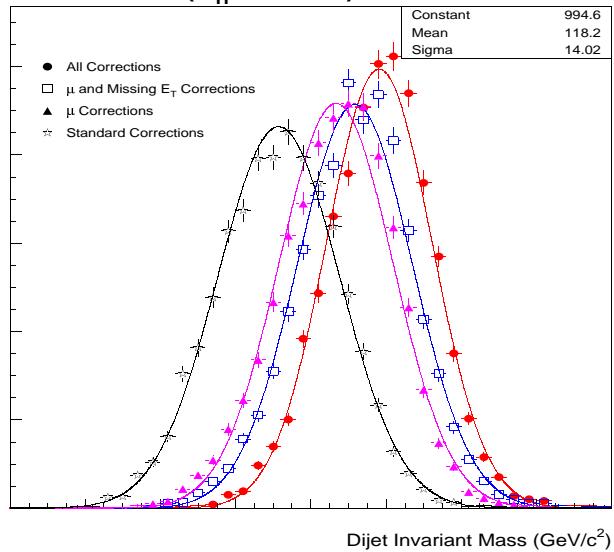


Alternative tight / loose scheme:



$b\bar{b}$ Mass Resolution

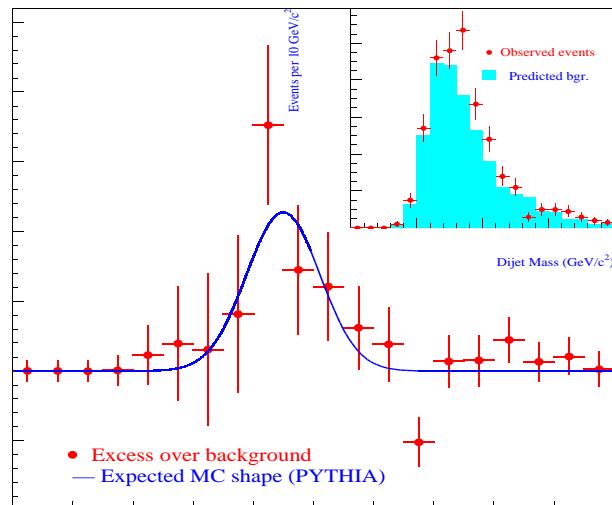
HERWIG H \rightarrow bb ($M_H=120$ GeV): Mass Reconstruction



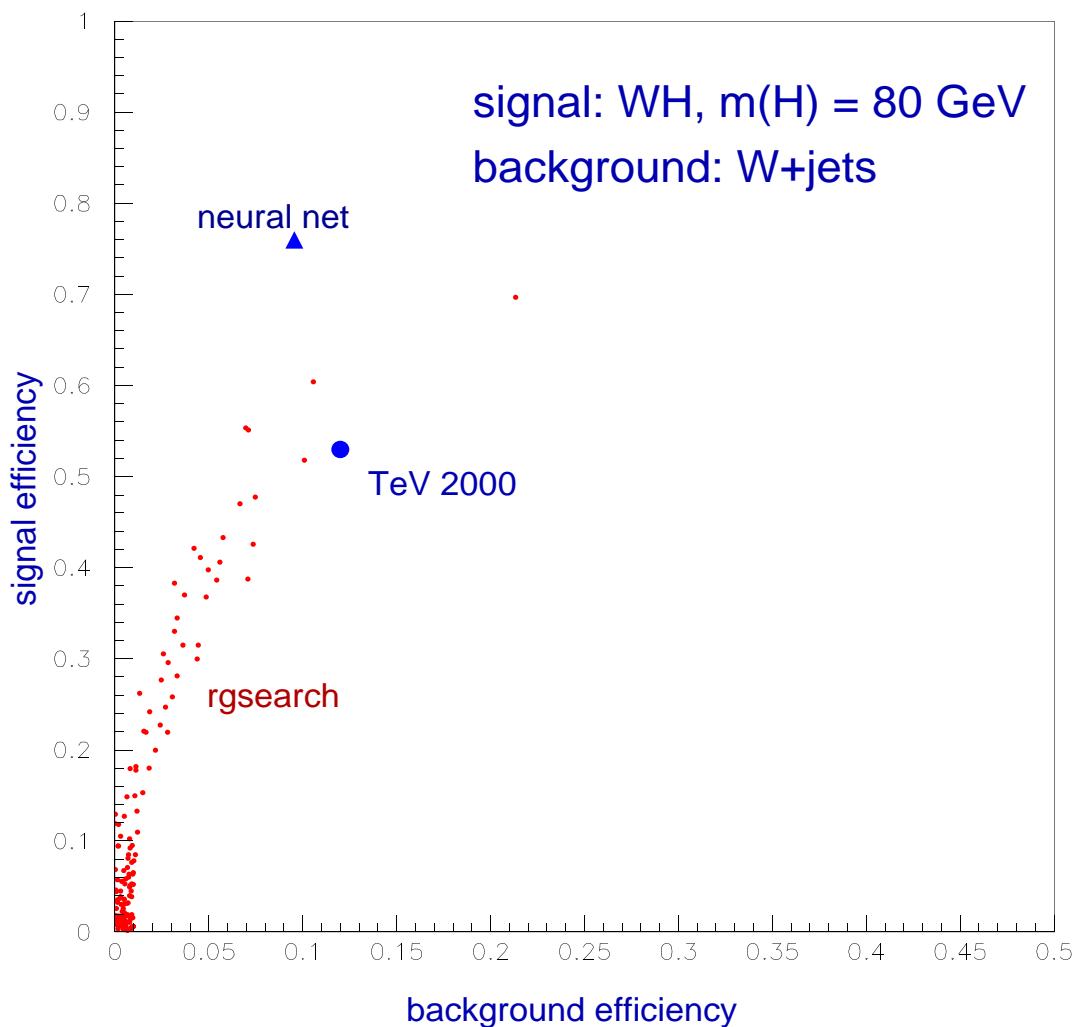
Make various corrections ...

Can see ...

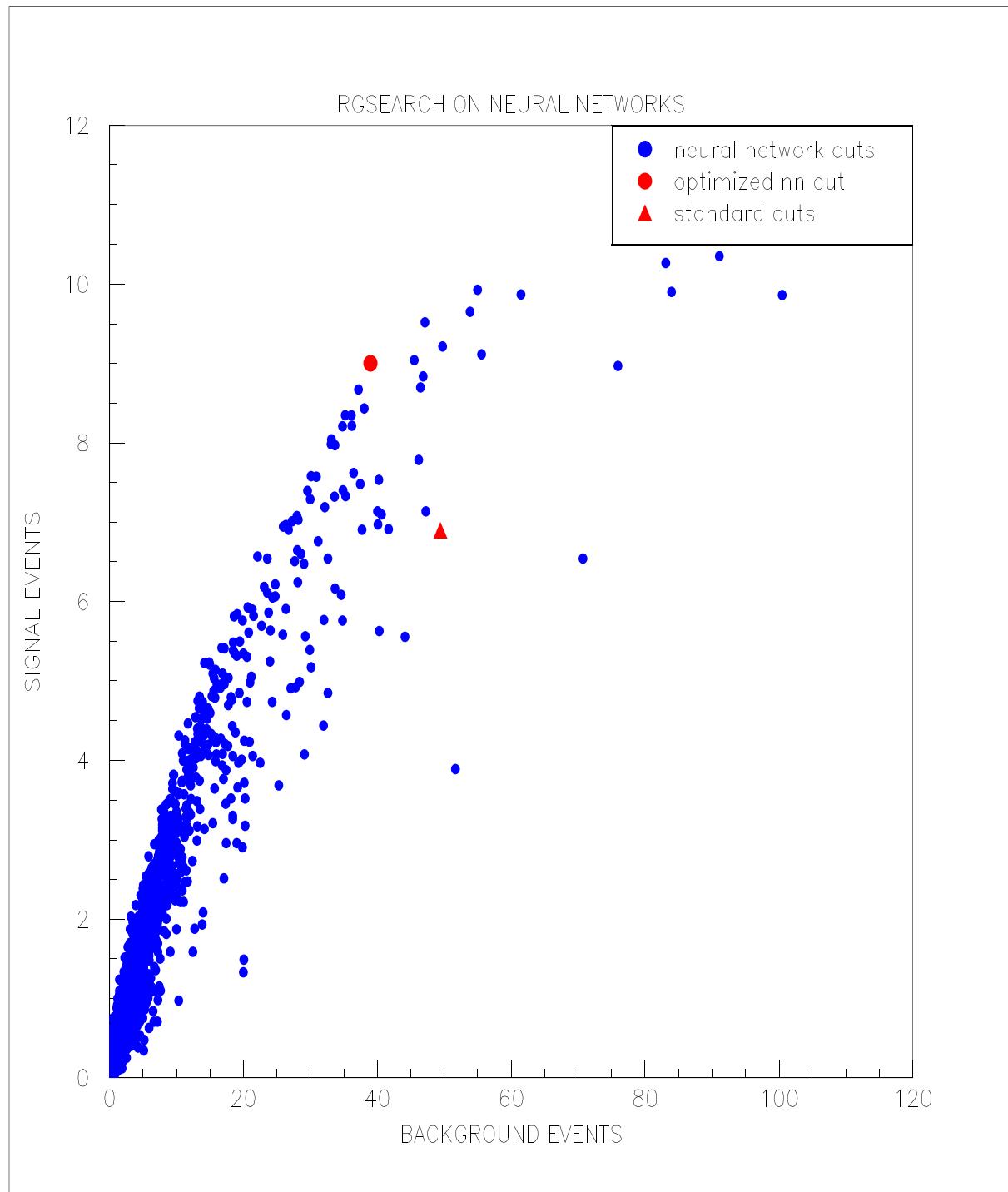
$$\rightarrow t \bar{t}$$



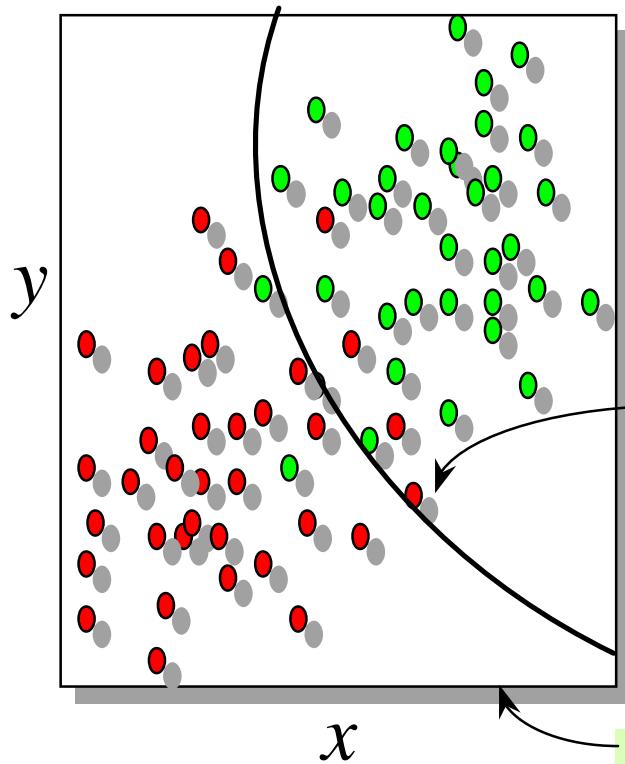
Optimal Event Selection



Optimal Event Selection



Optimal Event Selection



$$S = \bullet \quad B = \circ$$

$$r = \frac{p(x, y|S)p(S)}{p(x, y|B)p(B)}$$

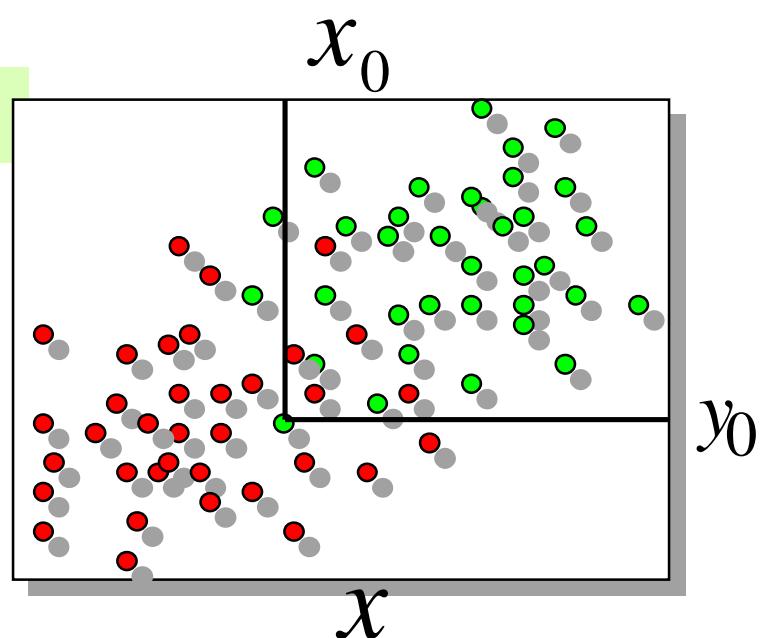
$r(x, y) = \text{constant}$
defines an optimal
decision boundary

Feature space

Conventional cuts

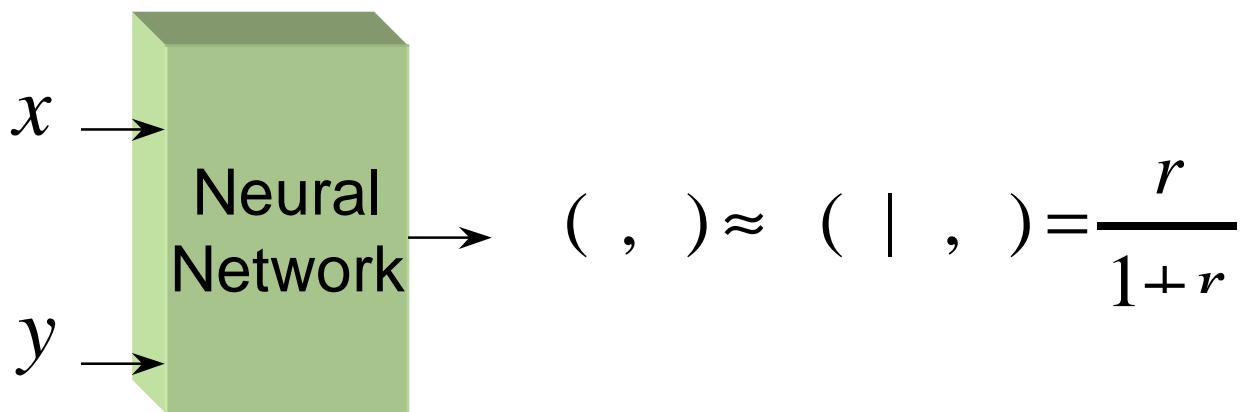
$$x > x_0$$

$$y > y_0$$



Event Selection Neural Networks

A feed forward neural network is a function that approximates the Bayesian posterior probability $p(s|x,y)$



Low Mass Higgs Channels

- **WH** ($M_H = 90$ to 130 GeV/c 2)

- Bkgds. σBR fb
 - WH 30 - 120
 - Wbb 3500
 - WZ 165
 - tt 2600
 - tbq 880
 - tb 107

$$p \bar{p} \rightarrow \nu \bar{\nu}$$

- **ZH** ($M_H = 90$ to 130 GeV/c 2)

- Bkgds. σBR fb
 - ZH 8 - 50
 - Zbb 668
 - ZZ 1235
 - tt 2600
 - tbq 880
 - tb 107

$$p \bar{p} \rightarrow \nu \bar{\nu}$$

NN Optimization: An Example

- **Signal**

- Pythia

- **Backgrounds**

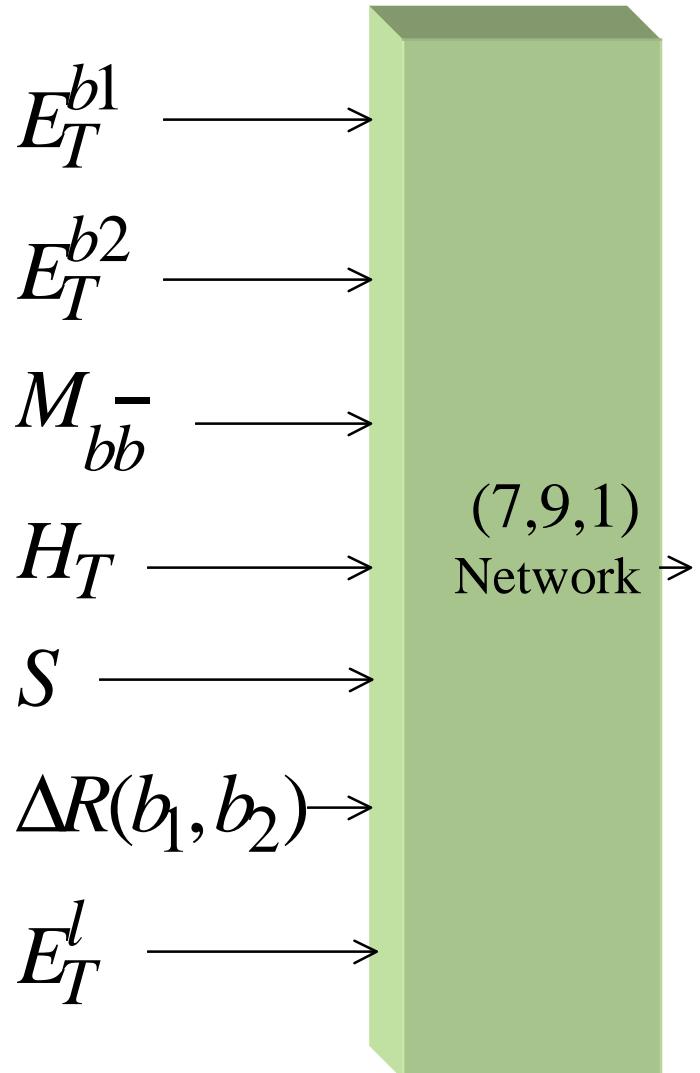
- CompHEP (Vbb)
 - Pythia

- **Detector
Simulation**

- SHW

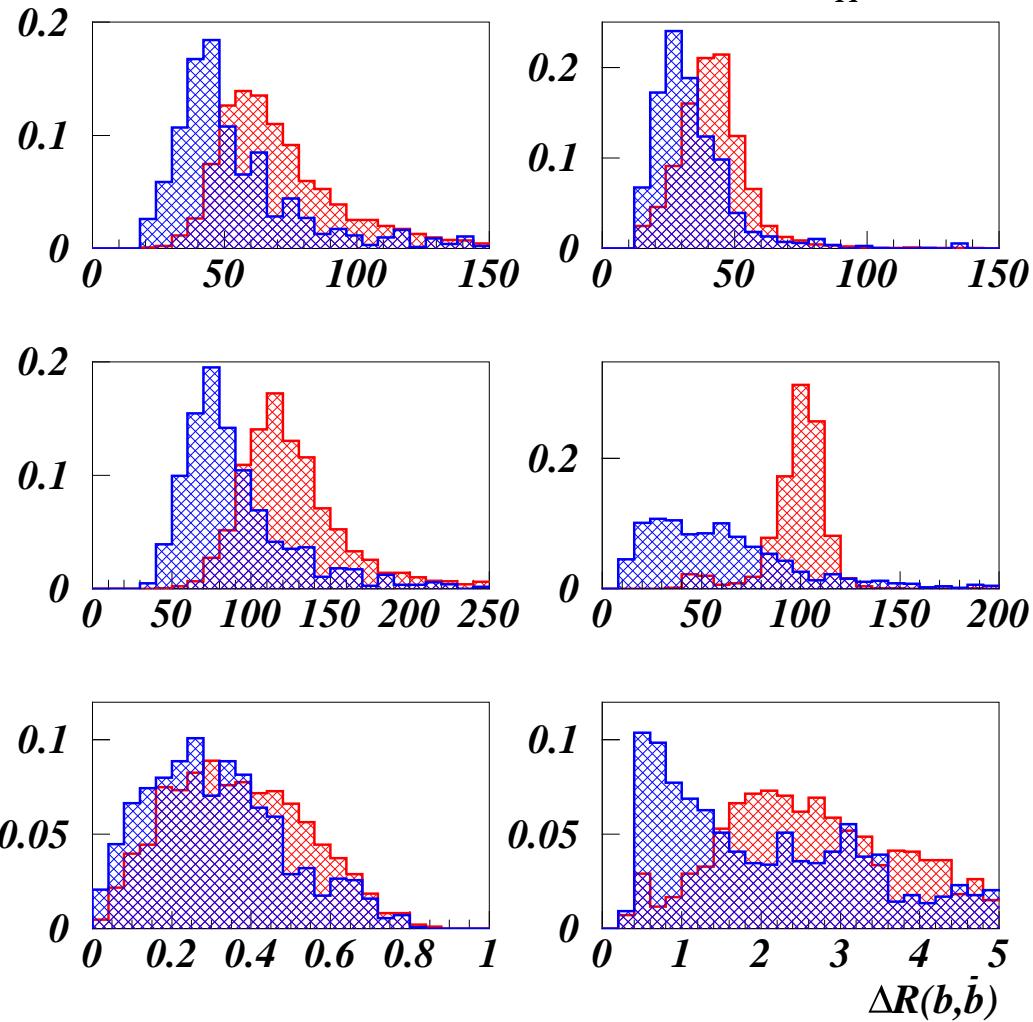
- **Networks**

- Jetnet (v3.0)
 - 3 Networks/ M_H
 - VH vs VZ
 - VH vs Vbb
 - VH vs tt
 - 3 cuts



W($\rightarrow l\nu$)H

$WH \rightarrow l\nu b\bar{b}$ vs $Wb\bar{b}$ $M_H = 100 \text{ GeV}/c^2$

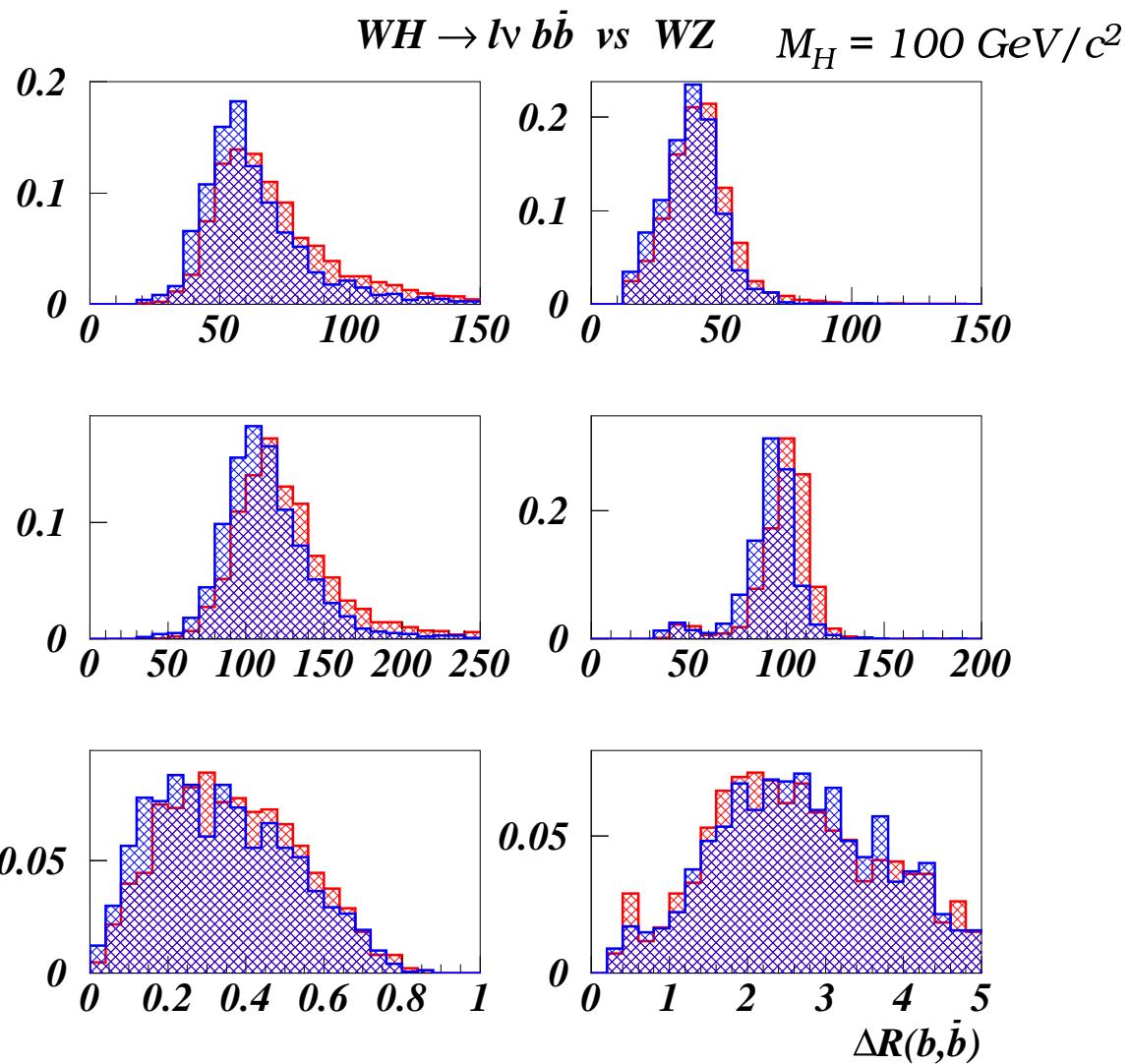


- **Initial cuts**

$$|\eta_l| < \eta$$

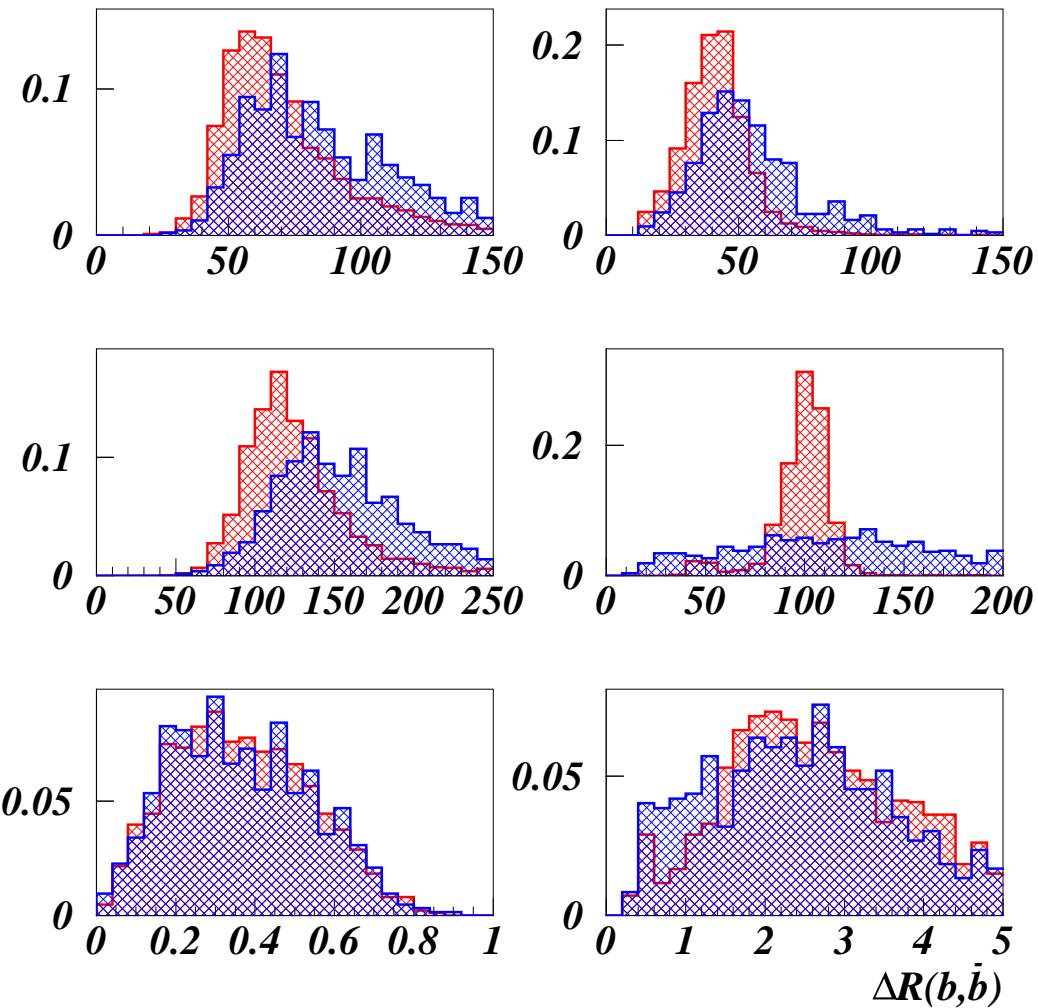
- **Assume two b-tagged jets**

W($\rightarrow l\nu$)H



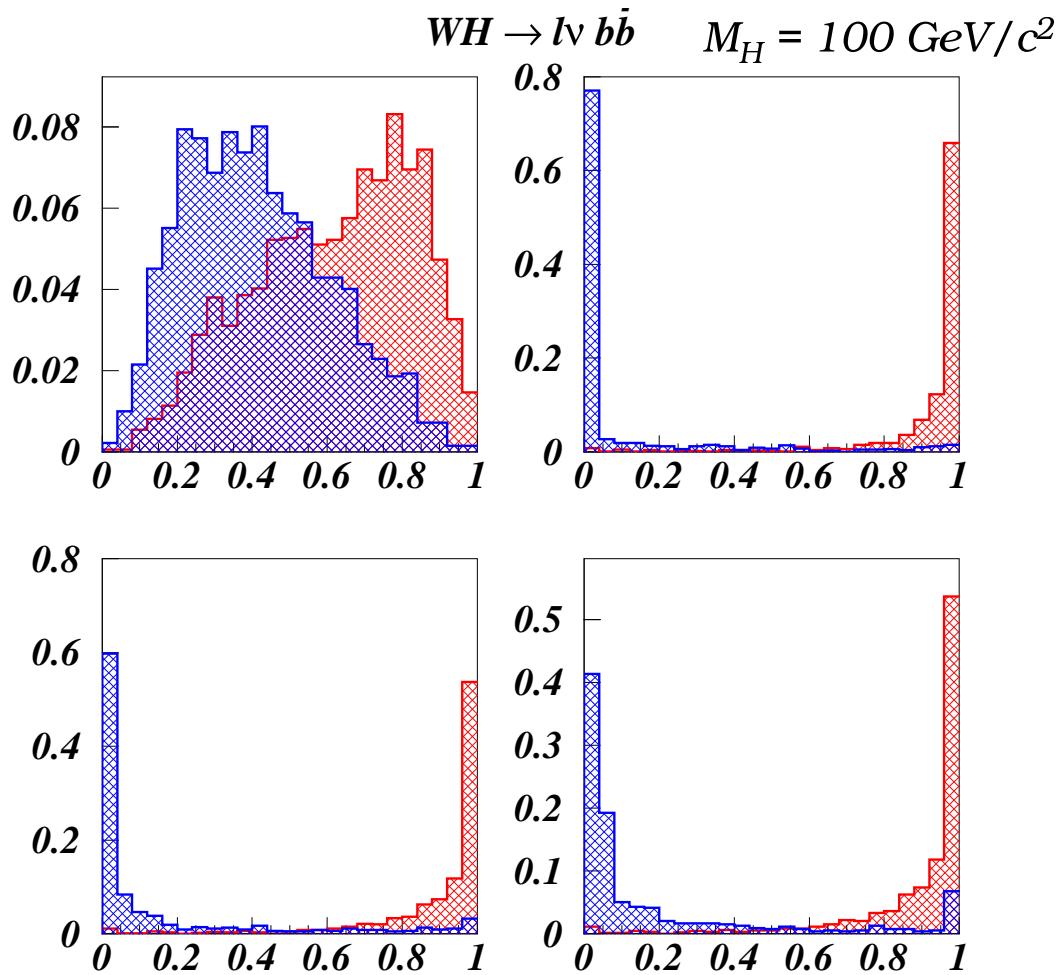
W($\rightarrow l\nu$)H

$WH \rightarrow l\nu b\bar{b}$ vs $t\bar{t}$ $M_H = 100 \text{ GeV}/c^2$



W($\rightarrow l\nu$)H (network outputs)

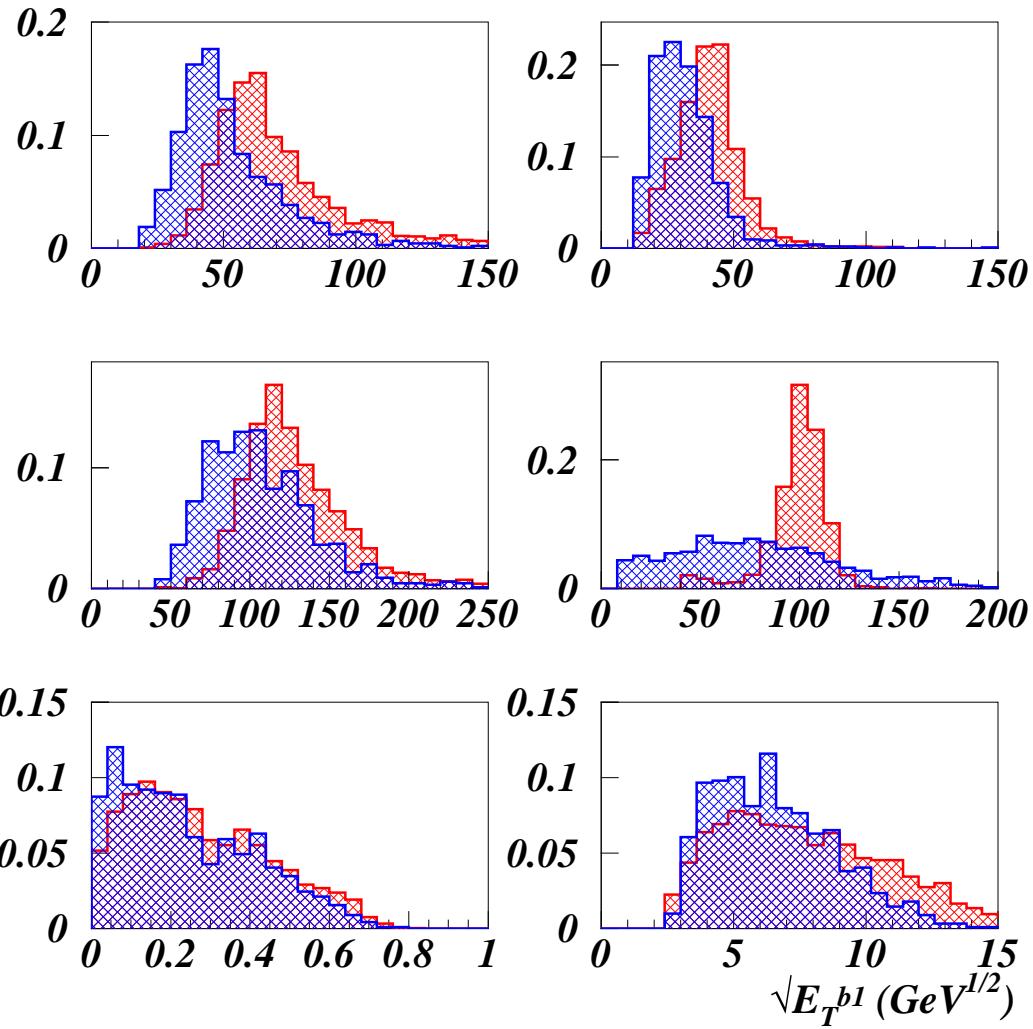
- Three networks at each M_H
 - WH vs WZ, WH vs Wbb, WH vs tt



- Diboson background is the most difficult to discriminate against at low M_H

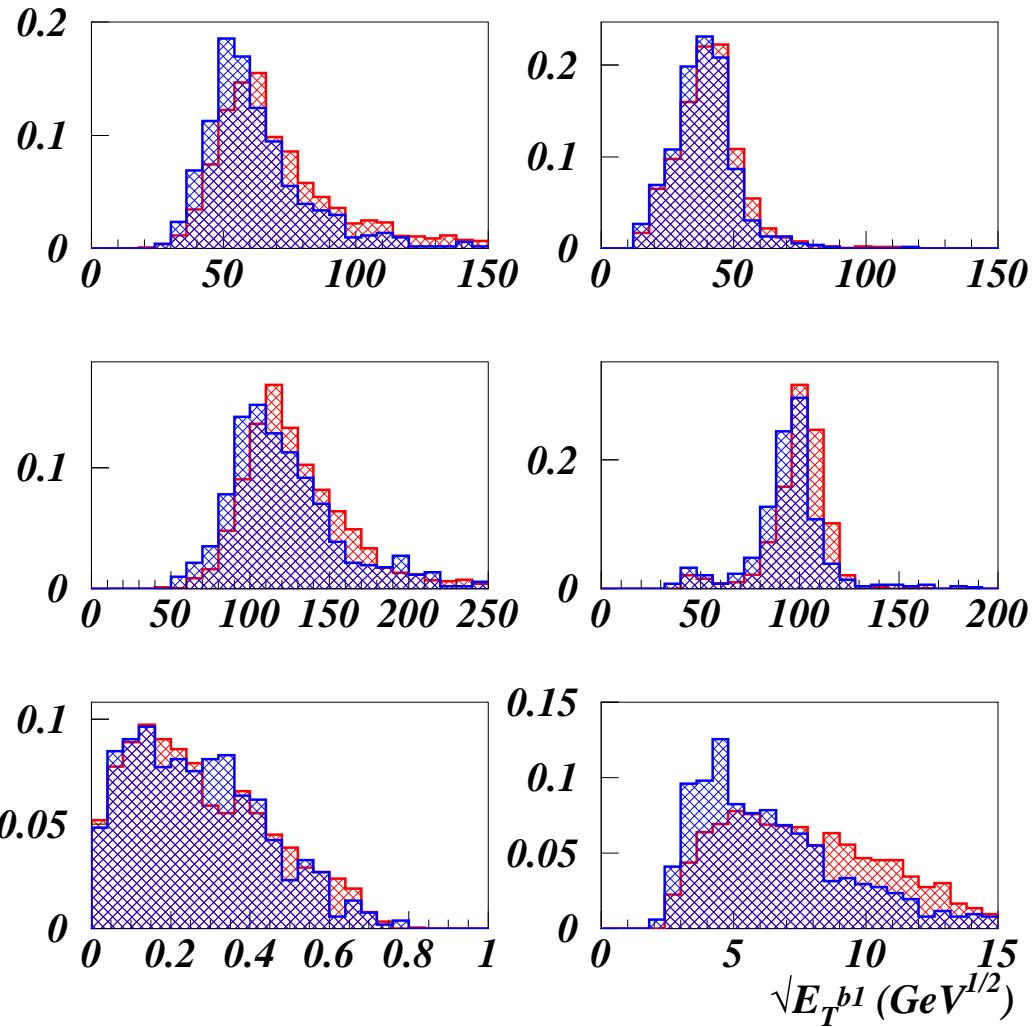
Z($\rightarrow \nu\bar{\nu}$)H

$ZH \rightarrow \nu\bar{\nu} b\bar{b}$ vs $Zb\bar{b}$ $M_H = 100 \text{ GeV}/c^2$

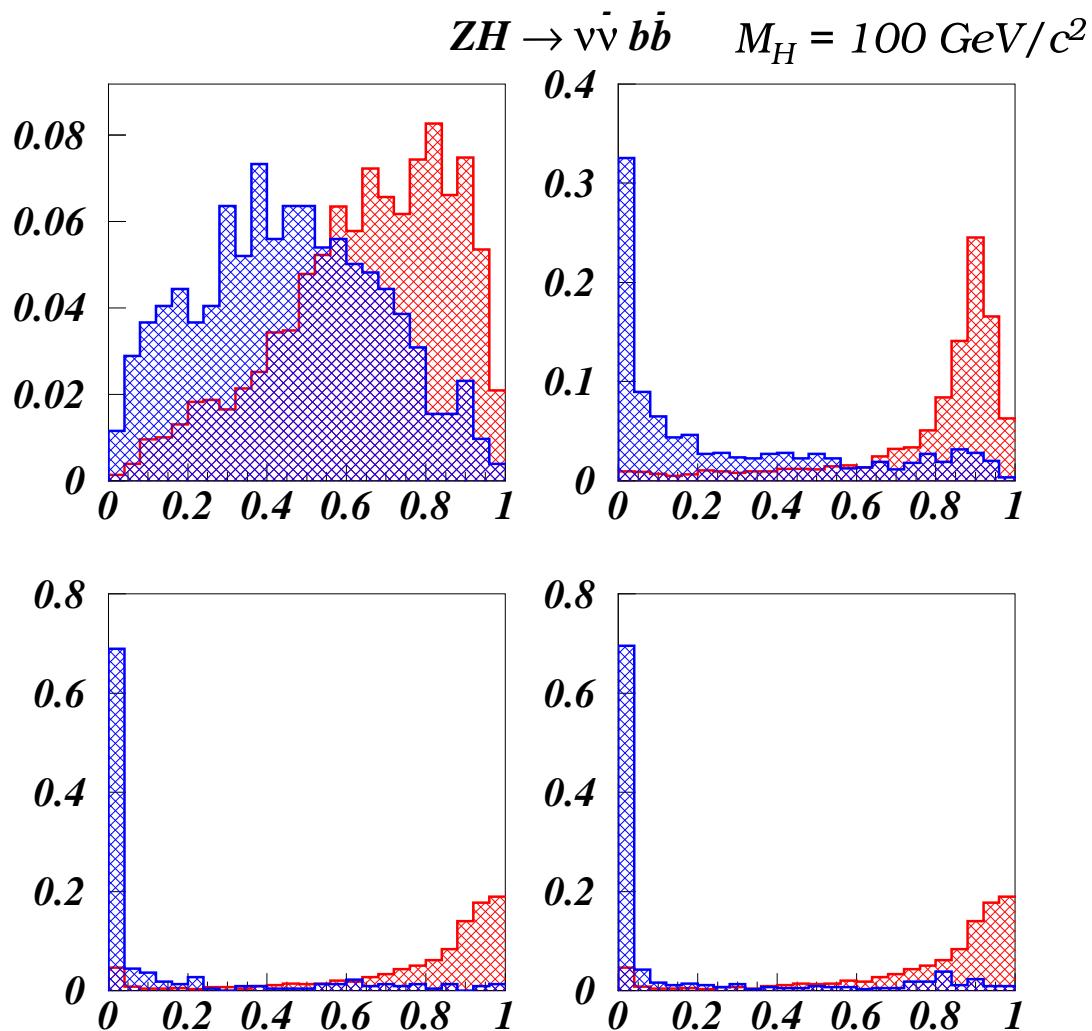


Z($\rightarrow \nu\bar{\nu}$)H

$ZH \rightarrow \nu\bar{\nu} b\bar{b}$ vs ZZ $M_H = 100 \text{ GeV}/c^2$



$Z(-\rightarrow \nu\nu)H$ Network Outputs



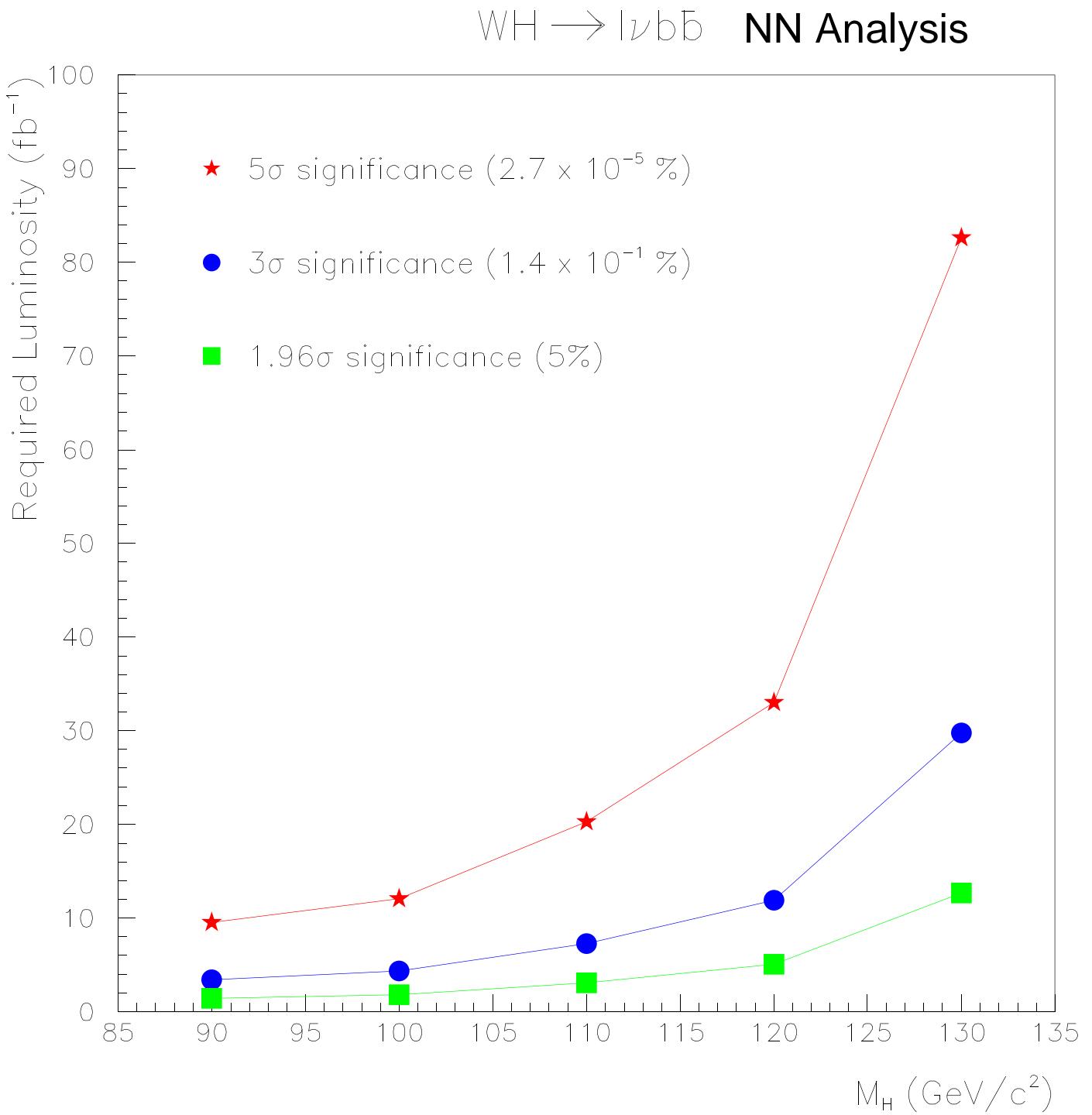
Results: WH, ZH

\sqrt{I}

with and without neural network:

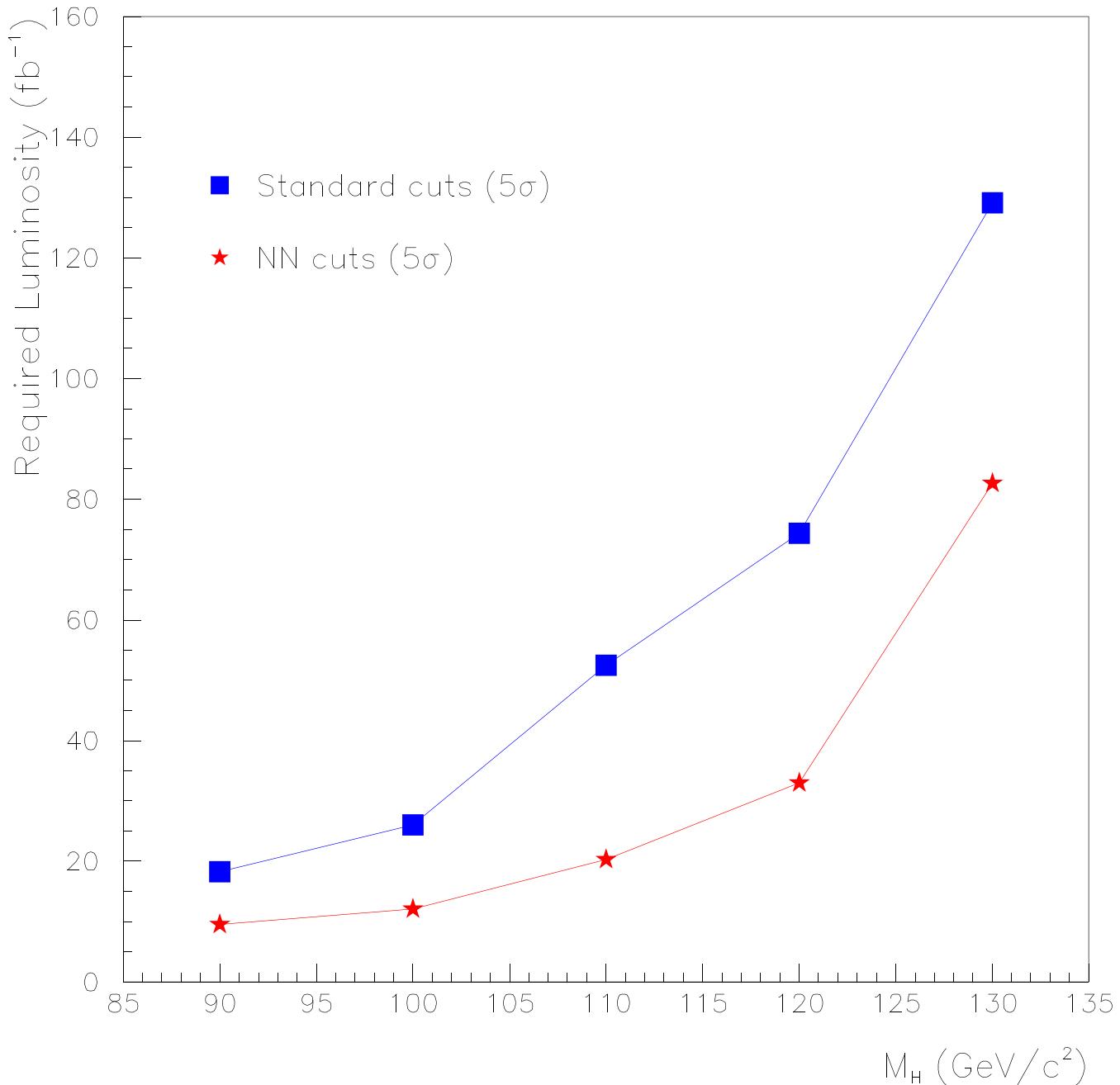
channel	mass (GeV)	standard cuts	neural net	L^{NN}/L^{std} (for 5σ obsv.)
$WH \rightarrow \ell v b \bar{b}$	100	0.98	1.44	0.46
	110	0.69	1.11	0.39
	120	0.58	0.87	0.44
	130	0.40	0.55	0.64
$\rightarrow \nu \bar{\nu}' \gamma$	100	1.02	1.27	0.65
	110	0.78	1.08	0.52
	120	0.59	0.84	0.49
	130	0.37	0.56	0.44

Results : $W H \rightarrow l\nu b\bar{b}$

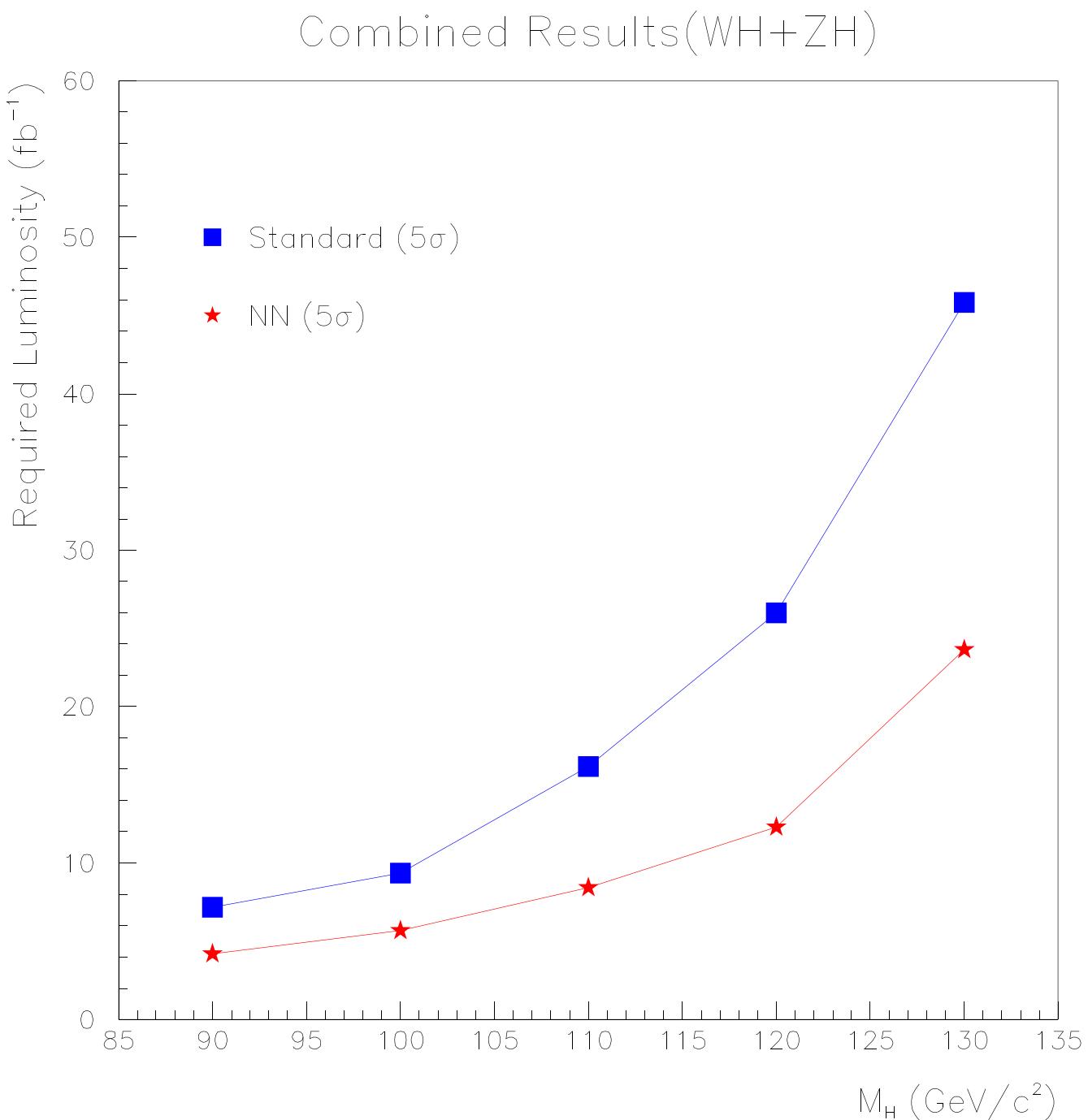


Results : $W H \rightarrow l\nu b\bar{b}$

$W H \rightarrow l\nu b\bar{b}$

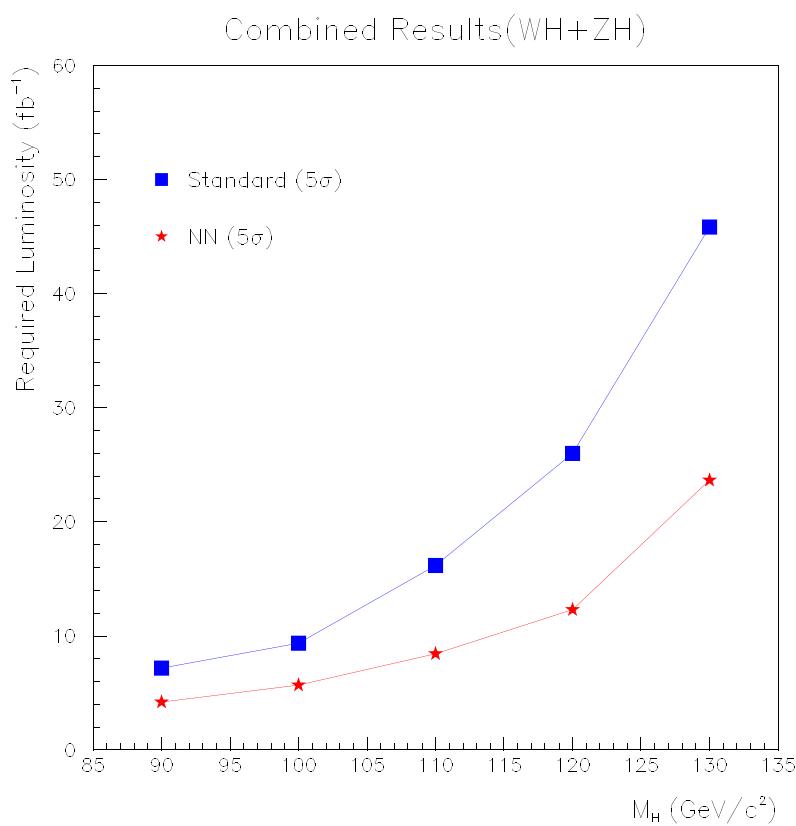


Results : WH+ZH



Combined Results (WH+ZH)

M_H (GeV/c^2)	100	110	120	130
Luminosity (fb^{-1})				
5σ (std. Cuts)	9.4	16.2	26.0	45.8
5σ (NN)	5.7	8.4	12.3	23.7
3σ (NN)	2.1	3.0	4.4	8.5



$h \rightarrow W^*W^*$ Channels

$p\bar{p} \rightarrow gg \rightarrow H \rightarrow W^*W^* \rightarrow \ell^-\bar{\nu}\ell\nu, \ell\nu jj$

$p\bar{p} \rightarrow WH \rightarrow WW^*W^* \rightarrow \ell\nu\ell\nu jj, \ell\nu\ell\nu\ell\nu$

$p\bar{p} \rightarrow ZH \rightarrow ZW^*W^* \rightarrow \ell\ell\ell\nu jj, \ell\ell\ell\nu\ell\nu$

Also, $p\bar{p} \rightarrow WH \rightarrow WZ^*Z^*$, $p\bar{p} \rightarrow ZH \rightarrow ZZ^*Z^*$

- Cuts on lots of variables

- Simple Variables
- Deduced / Intelligent Variables
- Genius Class (Likelihood) Variables

$h \rightarrow W^*W^*$ Channels

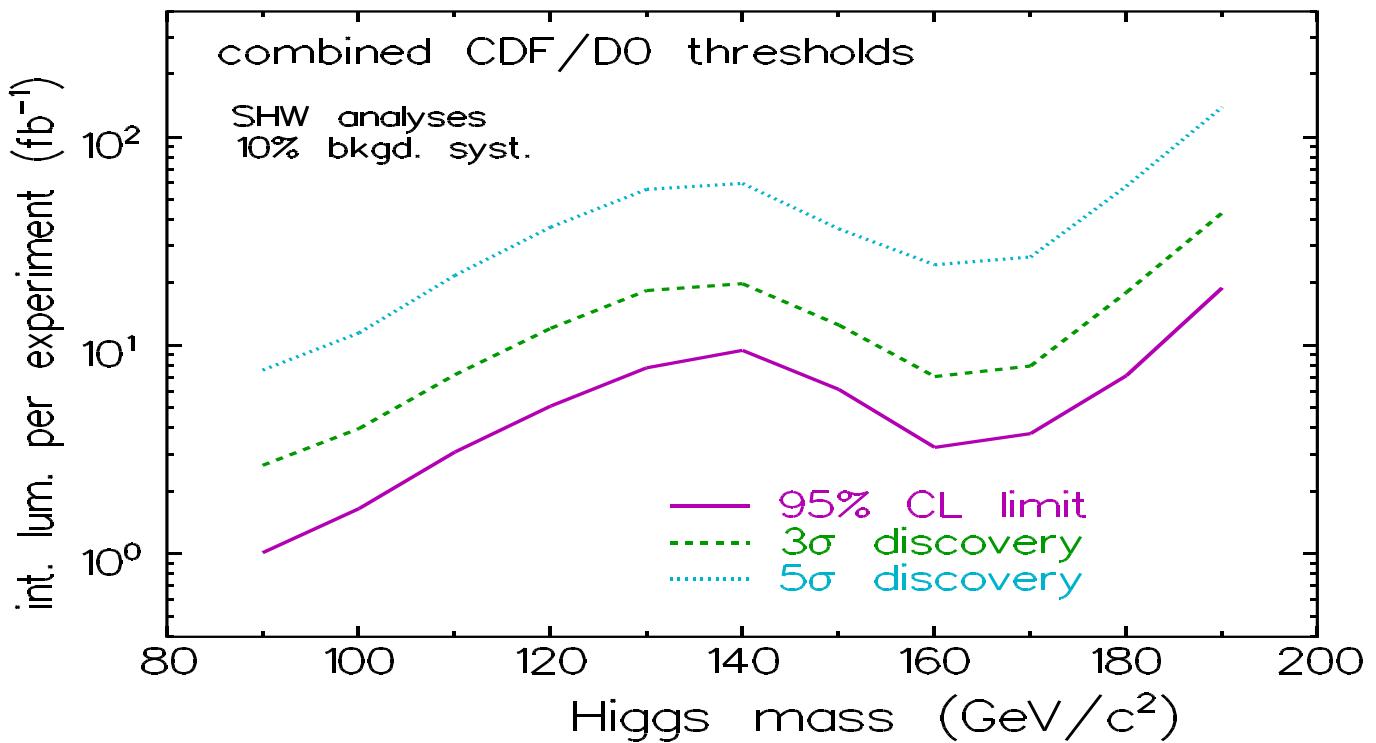
High-mass SM Higgs Channel Sensitivities

expected events and sensitivity in 1 fb^{-1}

channel	rate	Higgs mass (GeV/c^2)					
		130	140	150	160	170	180
$\ell^\pm\ell'^\pm\ell^\mp$	S	0.025	0.039	0.050	0.057	0.033	0.033
	B	0.025	0.025	0.025	0.025	0.025	0.025
	S/\sqrt{B}	0.16	0.25	0.32	0.36	0.21	0.21
$\ell^+\ell^-\nu\bar{\nu}$	S	-	2.6	2.8	1.5	1.1	1.0
	B	-	44	30	4.4	2.4	3.8
	S/\sqrt{B}	-	0.39	0.51	0.71	0.71	0.51
$\ell^\pm\ell^\pm jj$	S	0.15	0.29	0.36	0.41	0.38	0.26
	B	0.58	0.58	0.58	0.58	0.58	0.58
	S/\sqrt{B}	0.20	0.38	0.47	0.54	0.50	0.34

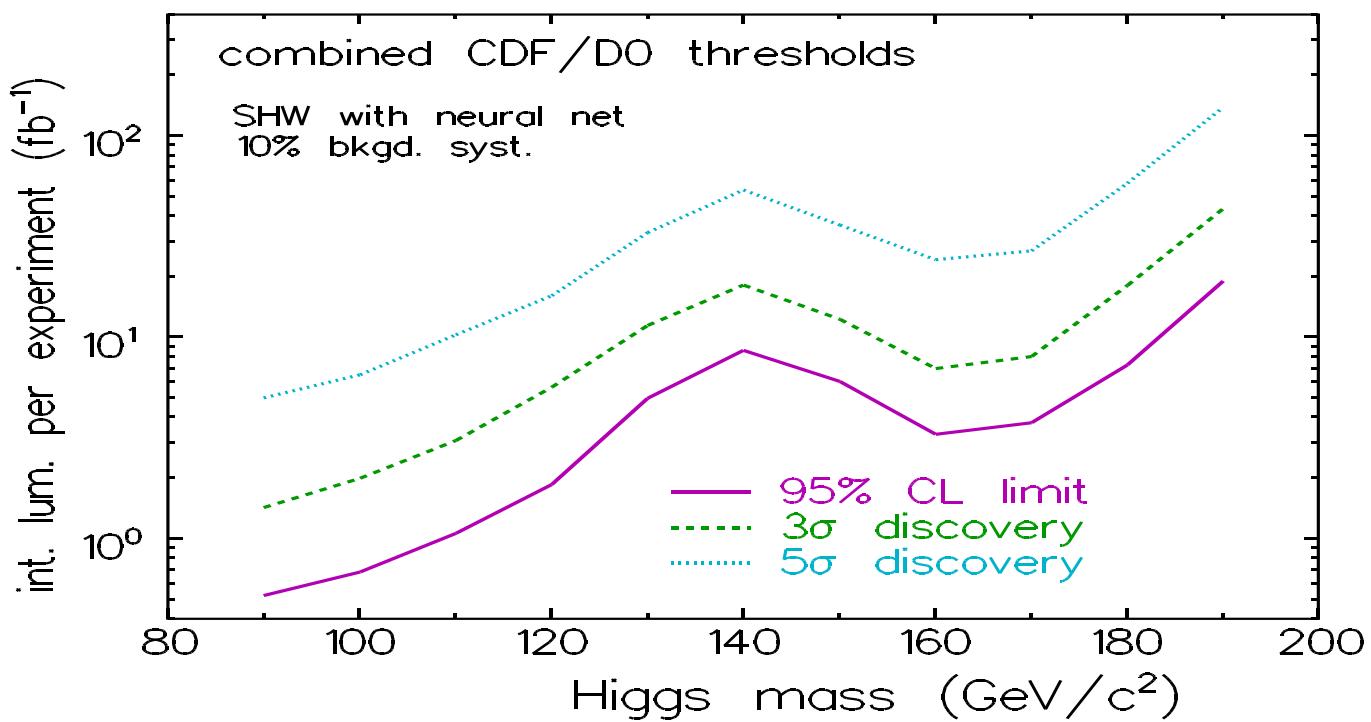
Combined Results

- Bayesian combination method - two experiments
- 30% better $m_{\tau^+ \tau^-}$ resolution than Run 1
- SHW acceptance
- nominal systematic errors: 10% or $1/\sqrt{\tau p_T}$



SM Higgs: Combined Results

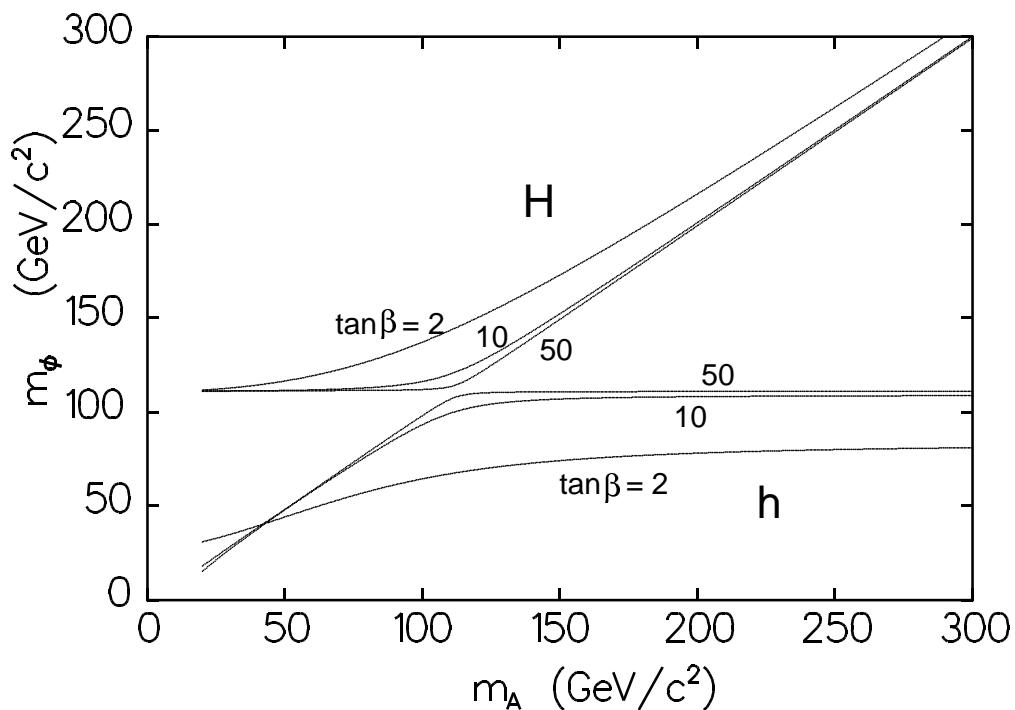
- Bayesian combination method - two experiments
- 30% better m_{H}^{\pm} resolution than Run 1
- SHW acceptance
- nominal systematic errors: 10% or $1/\sqrt{\text{lum}}$



SUSY Higgs (MSSM)

Have five Higgs bosons: h, A, H, H^\pm

Masses governed by two parameters: m_A , $\tan \beta$

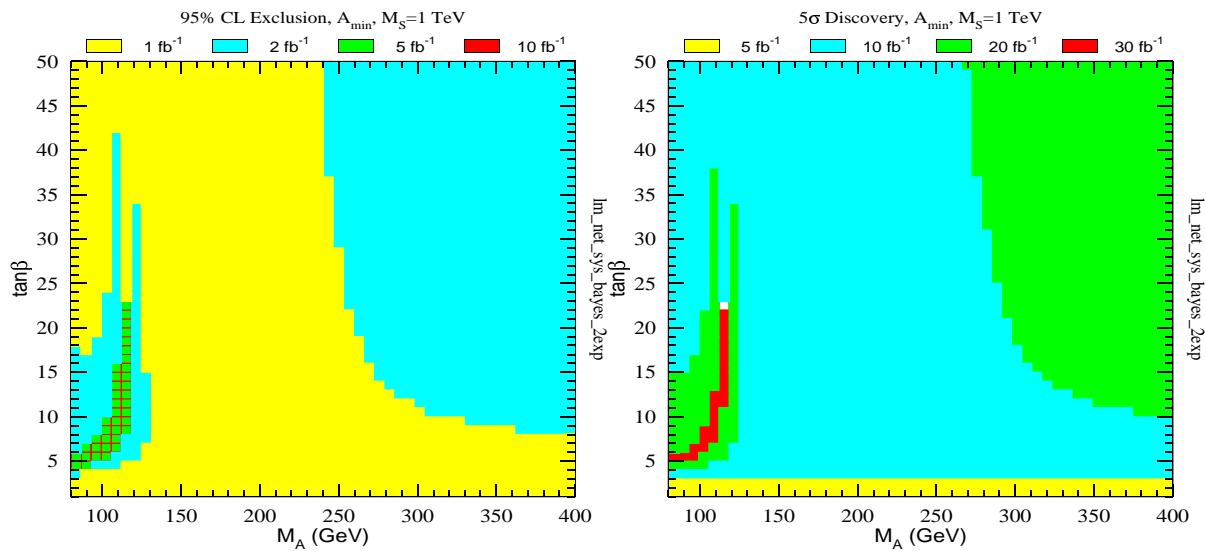


→ Vh, VH can be Standard Model-like

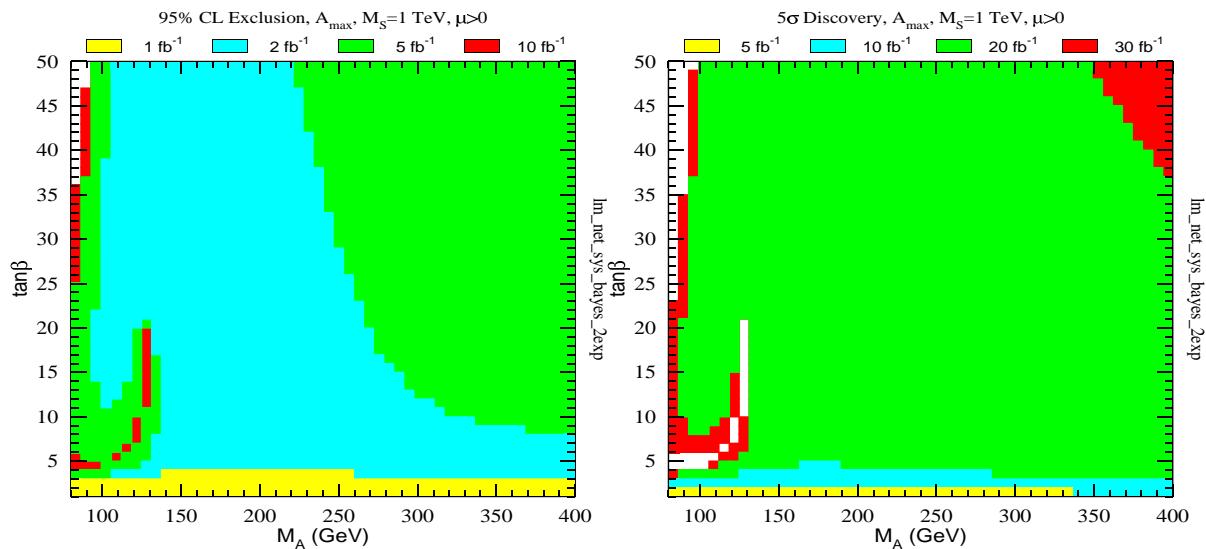
→ apply SM Higgs search to MSSM parameter space

MSSM discovery/exclusion from SM Higgs channels

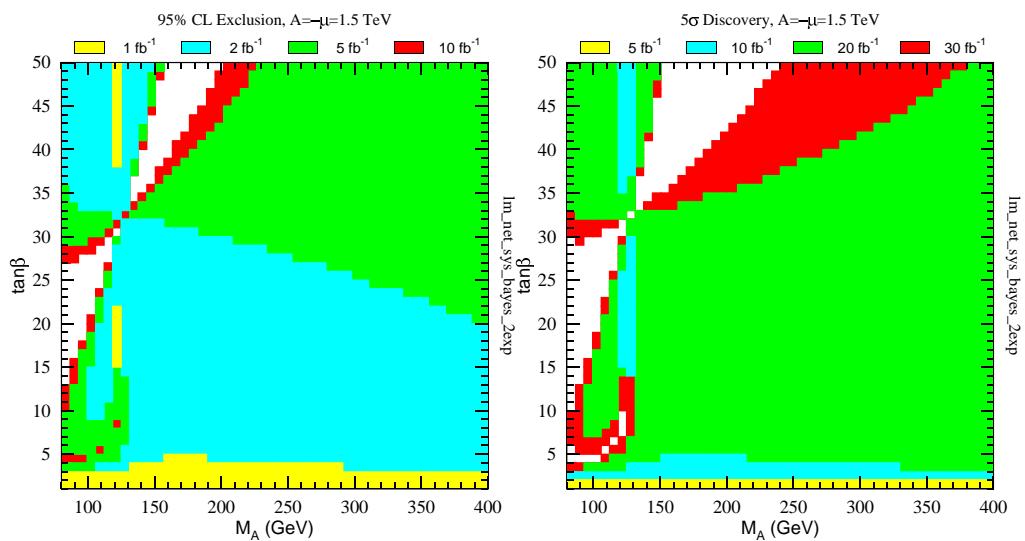
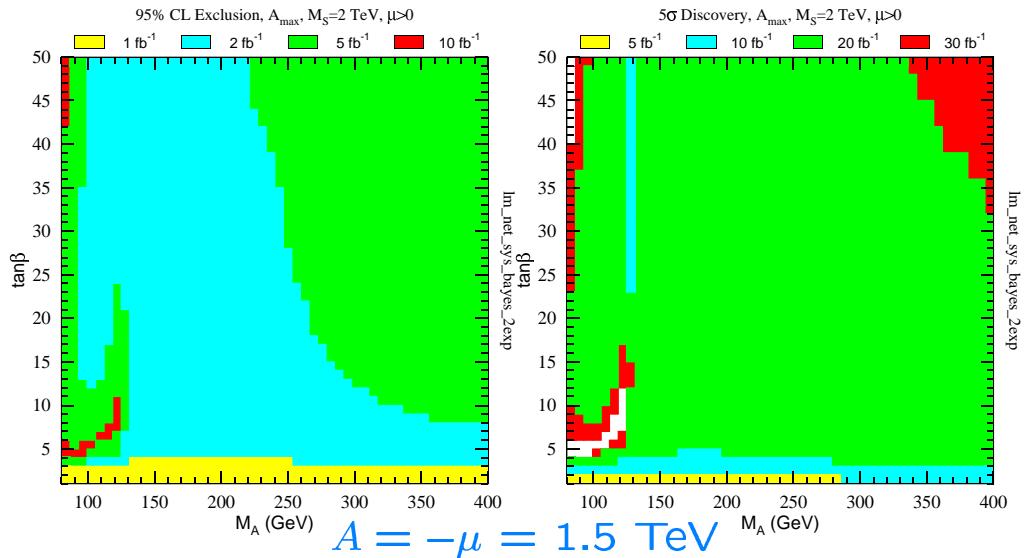
A_{min}, M_s = 1 TeV



A_{max}, M_s = 1 TeV



$A_{max}, M_S = 2.0 \text{ TeV}$



Conclusions

- If a low-mass Higgs boson exists then its discovery may be within reach of the Tevatron.
- An NN based search of the WH and ZH channels reduces by 40-50% the required luminosity for a 5σ discovery, relative to other methods.
- Combining all channels and both experiments is crucial.
- If there is no SM Higgs we can exclude it at 95% CL up to 120 GeV mass in Run 2, and with 10 fb^{-1} can extend the exclusion up to 190 GeV mass.
- If there is a Higgs, we can discover it at the 3 - 5σ level with $10 - 30 \text{ fb}^{-1}$ per experiment, up to 190 GeV mass.